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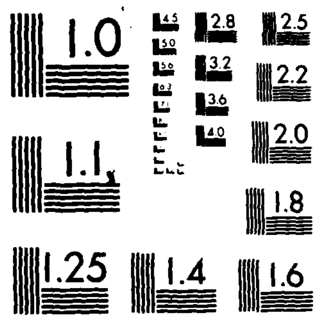

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PERLAB-3

Detection of Dotted Forms in a Structured Visual Noise Environment

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1 MARCH 1984

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Five experiments are described which explore the human observer's ability to detect single dotted lines masked by other dotted lines. Stimuli are presented tachistoscopically on a computer controlled cathode ray tube. Results indicate that: 1) Rotations of the stimuli, relative to the orientation of the noise lines, improve detection performance only if the rotations are made around the Z axis. Rotations around the Y axis fail to improve detection performance. 2) The mechanism involved in the detection of dotted forms uses different strategies or algorithms depending upon the

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density of the noise mask. 3) Orienting the stimulus and masking lines to other than the horizontal decreases detection performance. The results are discussed in the context of a model incorporating a variable aperature attentional process.

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Abstract

Five experiments are described which explore the human observer's ability to detect single dotted lines masked by other dotted lines. Stimuli are presented tachistoscopically on a computer controlled cathode ray tube. Results indicate that: 1) Rotations of the stimuli, relative to the orientation of the noise lines, improve detection performance only if the rotations are made around the Z axis. Rotations around the Y axis fail to improve detection performance. 2) The mechanism involved in the detection of dotted forms uses different strategies or algorithms depending upon the density of the noise mask. 3) Orienting the stimulus and masking lines to other than the horizontal decreases detection performance. The results are discussed in the context of a model incorporating a variable aperature attentional process.

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Introduction

In recent years the question of the locus of the physiological mechanisms responsible for producing experimentally induced visual masking has been raised and experimentally explored (Uttal, 1970; Turvey, 1974). The question of locus is important not only in its own right, but also because it provides information about the nature of the processes that produce visual masking effects. If the locus of the visual masking effect is in the peripheral retina and/or lateral geniculate nucleus then the masking effect is probably the result of relatively simple neural interaction processes. Examples of the kinds of visual masking that seem to be due to the effect of peripheral neural interaction processes are masking of a stimulus with a bright diffuse light and masking of a stimulus with overlapping stimuli. In both of these experimental paradigms the masking effect appears to be specifically due to a lateral inhibitory mechanism in the retina. Experiments performed using these paradigms, therefore, give us information about the factors which influence information transmission in the periphery. Specifically, these experiments provide information about a peripherally based filtering system whose function appears to be to sharpen the contrast between contours. Visual masking of this kind appears to result from an overloading of this filtering system.

Alternately, if the locus of a visual masking effect is more central, then the experimental effect may be due to much more elaborate information intergation processes. The ability to read through the mask in this case may depend on information extraction consisting of statistical or algorithmic processing of information from the visual system's input. Information extraction of this kind may thus be considered to exemplify processes involving the separation of figures from grounds or the extraction of specific features from a complex stimulus input. Such a process might involve the recoding of the information into a categorical

form and would be certainly be carried out at a very high level in the nervous system. A possible example of an experimental effect that may be due to a high level information intergating process is the metacontrast phenomena. In metacontrast the masking effect may be due to a process that acts as a gate. According to this hypothesis the incoming information has already been separated into a figure and ground and is passing through a gate whose function is to only pass updated locative information about objects. The gate passes the second presentation, which represents the updated locative information, while suppressing the first presentation, which is dealt with as if it was the same object at a earlier location in time.

If we are to be to discover how the human visual system perceives form we must explore these higher level processes and discover the specfic algorithms used in form perception. The experiments reported here are an attempt to discover evidence of these algorithms by exploring the mechanism(s) involved in detecting dotted forms. They belong to the class of visual masking experiments that use random patterns of dotted dynamic visual noise to mask dotted geometrical forms, a technique pioneered by French (1953) and further developed by Uttal (1970; 1975; 1983). Within this experimental paradigm the component parts (the constituent dots) of the masking noise and the test stimulus are identical. Also, as presently used, each presentation is designed so that the test stimulus and the masking noise overlap in space and time. The specific detection performance question explored in this study is the effect that configured noise consisting of dotted lines has on the detection of dotted test stimuli, also organized into linear stimulus forms.

Dotted stimuli have certain advantageous properties. First, dots positioned at random locations and projected at moderate speeds are unlikey to stimulate the same retinal loci successively. This property effectively eliminates any masking effect do to the photochemical properties of the retina receptors. Second, no

lateral inhibitory interaction among the dots is elicited by this procedure for two reasons. The first is that small dots at suprathreshold luminosities are known to interact only weakly (von Bekesy, 1968). Additionally, tachistoscopic exposures (15 msec) do not allow sufficient time for the elicitation of the lateral inhibitory interaction mechanism. Third, dotted patterns and dotted noise are both weak stimuli for eliciting responses from contour sensitive systems (Held, 1970; Uttal, 1970). Finially, dotted forms are defined only by the organizational properties of the individual dots of which they are composed. This property allows the experimenter to study the organizational parameters which influence detection independent of other extraneous cues. These unique properties of the dotted stimuli combine to allow the experimenter to conduct a relatively pure examination of an intermediate level visual pattern detection process relatively unconfounded by the effects of peripheral mechanisms and also by more elaborate and higher level cognitive processes.

Currently, much of the effectiveness of many kinds of visual masking is attributed to peripheral variables such as lateral inhibition (Higgins and Knoblauch, 1977; Beyerstein and Freeman, 1977) or contour overlap between between stimulus and noise (e.g. Sekuler, 1965; Parlee, 1968). If similar masking effects can be demonstrated using the dot detection paridigm it would be suggestive that these masking effects are not due to peripheral variables alone, but involved more central processes as well.

Sekuler (1965) has investigated the masking of a stimulus bar with a masking pattern of alternating bright and dark bars. The effect of angular difference between the stimulus bar and the masking pattern was explored using both horizontal and vertical test stripes. Sekuler found that the masking effect of the masking pattern of bars fell off sharply as the masking pattern was rotated past 15 degrees in either direction (plus or minus) with respect to the stimulus bar. Parlee

(1968), in a similar experiment, demonstrated a similar masking effect using a single vertical stimulus line and a single masking line. Parlee also found that the masking effect of the masking line fell off sharply as the masking line was rotated past 15 degrees in either direction. In both of these experiments the masking effect was attributed to the interacting contours of the stimulus line and masking line. As the masking line was rotated, there was less interaction resulting in less masking. If a similar masking effect could be demonstrated using the dot detection paradigm it would suggest that at least some of the masking effect is due to a more central cognitive mechanism since no contours exist, only those constructed from the organization of the dots in the line.

A second question to be explored is whether or not visual space is isotropic. Uttal (1983), using the dot detection paradigm has suggested that "visual space is homogeneous, symmetrical and isotropic". This is based upon his findings that observers are insensitive to line orientation and direction in both two (Uttal, 1975) and three (Uttal, 1983) dimensions when dotted forms are used. These findings are in sharp contrast to what other researchers have reported, as summarized by Appelle (1972). The majority of these studies found significantly higher observer performance when visual stimuli where vertical or horizontal as opposed to oblique.

One possible solution to these conflicting results is offered by the nature of the stimuli used. The vast majority of the experiments summarized by Appelle (e.g. Sulzer and Zener, 1953; Onely and Volkman, 1958; Rochlin, 1955; Andrews, 1967) used solid lines as the stimuli (though there were important exceptions e.g. Smith, 1962). Appelle, after reviewing these experiments, suggested that the "oblique" effect might be due to the relative number of cells in visual cortex responsible for analyzing stimuli in either the vertical and horizontal or in the oblique orientation. This argument was supported by the work of Pettigrew, Nikara and Bishop (1968) who had neurophysiologically sampled a cell population in the

visual cortex of a cat (area centralis) and found that these cells had a distinct preference for vertical or horizontal stimuli. Since it is unlikely that dotted line stimuli activate line detectors in the visual cortex, it is possible that these conflicting results could be due to the nature of the different stimuli used. Solid lines might be activating line detectors, whereas the dotted stimuli might be activating another mechanism.

An alternate explanation would involve differences in the experimental paradigm used by Uttal and those researchers summarized by Appelle. Many of the researchers cited by Appelle (e.g., Sulzer and Zener, 1952; Only and Volkm. 1958; Andrews, 1967) used an experimental procedure that required the subject tate a line until it was parallel to a reference line. It is possible that this edure (and this is only one example of several procedures used) was measuring so. thing different than the detection mechanism measured by Uttal. If the different experiments were measuring different mechanisms, then the results are not in conflict but, rather, are complementary.

This question of the effect of orientation, and the two possible answers to the question of what causes the differences — stimulus type or method — will be investigated in two ways in this study. The first will be a more thorough investigation of the effect of orientation. Uttal's two dimensional research (1975) used dotted stimulus lines in four orientations: vertical, horizontal, oblique right and oblique left. Uttal's three dimensional work (1983) also used dotted stimulus lines limited to four positions. All ran diagonally from one corner to it's opposite (e.g., lower right front to upper left rear, upper left front to lower right rear, etc.). In the experiments of this current research we will use three different stimulus lines, which differ in their interdot spacing, to investigate the effect of orientation changes around both the Y and Z axes. In different experiments the three stimulus lines will be rotated around the two axes in small steps to determine if observer's

detection performance varies as a function of the orientation difference between the stimulus and the masking lines.

An additional difference between the present work and the earlier research is the nature of the visual noise mask that is used. Uttal (1975, 1983) used random patterns of dots to mask the stimulus forms. In the experiments now to be reported random patterns of dotted lines will be used as the mask. These noise lines differ from the stimulus lines in the number of dots of which they consist — four dots in a noise line compared to seven dots in a stimulus line — and in their interdot spacing distance. A main goal of this research is to determine if the addition of structure, i.e., linear organization, to the mask changes the experimental results. The task becomes more of a discrimination task instead of a detection task when the mask consists of lines, but the subject must still determine which of two presentations contains the stimulus form. This is, of course, all complicated by the similiarity of the stimulus and structured masking lines.

If the observer's performance is not effected by either the orientation of the stimulus line or the dimension in which the orientation change occurs, it would suggest that the differences between Uttal's results and those summarized by Appelle are due to the nature of the stimuli used; dotted lines are simply processed differently than are solid lines. Alternately, if the observer's performance is now dependent upon the the orientation of the stimulus or the dimension in which the orientation change occurs it would suggest that the differences are due to the nature of the experimental paradigm used.

The final variable to be explored is the effect of interdot spacing distance. Earlier work by French (1953) and Uttal (1970) has shown interdot spacing to be a powerful variable in defining the level of detection performance. In the present study we will be using three interdot distances in the stimulus lines. This allows us to measure the attributes of the dot detection mechanism. As mentioned, dotted

forms are defined solely by the organization of the individual dots of which they are composed. The dot detection mechanism "creates" a stimulus "line" by some type of analysis of the interrelationships between individual dots. Questions arise as to the parameters of the stimulus to which this mechanism is sensitive. It is anticipated that the use of three interdot distances in the stimulus lines will also shed light on the functional properties of this dot detection mechanism.

METHOD

Observers

Undergraduates of the University of Michigan served as paid observers. Eight observers participated over the course of these experiments. None of the eight had had prior experience detecting stimulus forms in visual masking noise. Each was tested for normal stereoscopic vision with an anaglyphic screening procedure using figures 1.0-1, 2.4-1 and 8.1-2 from Julesz (1971). Each of the observers was given three one hour pretraining session to familiarize them with the set of stimuli being used in each experiment. Experiments 1, 2, 4 and 5 each utilized four observers. Three observers participated in experiment 3.

Procedure

The observer is presented with two sequential one second presentations seperated by a one second blank period. Each presentation displays a dichoptic pair of images. When perceptually fused these images create the impression of a cubical volume. The stimuli are viewed through rotating prisms that are adjusted for the most comfortable convergence. A dotted stimulus form is hidden by

varying numbers of randomly placed dotted noise lines in one of these presentations. The other presentation contains two additional noise lines in order to maintain the luminosity of both presentations at equal levels. The noise lines are presented serially at equal temporal intervals. The temporal interval is dependent upon the number of noise lines per presentation. Increasing the number of noise lines decreases the temporal interval. This stimulus form is always presented in the center of the "cube", at the temporal midpoint (.5 sec.) of one or the other (randomly determined) presentations. The observers task is to specify in which of the two presentations the stimulus form is present and to indicate by depressing one of two hand held push buttons.

The observer signs on at the computer console to intiate the experimental procedure. The first experimental trial begins when the observer signals his readiness by pressing either of the two triggers. Each trial consists of two presentations, one with the stimulus and noise, the other only with noise. A dim single dot appears before each presentation at a fixation point in the center of the cube. After the two presentations the observer signals his choice to the computer. The computer program then determines if the choice is correct or not and displays a plus (if correct) or a minus (if wrong) to the observer. The computer also records the result for later statistical analysis. Another trial is then automatically initiated.

Each day an observer participates for approximately one hour and makes approximately 600 responses. At the end of each session a preliminary statistical analysis is automatically performed on each observer's performance; at the end of each day all observer's performances scores are pooled together and a more complete analysis is carried out. The density of the mask, measured in terms of the number of dotted visual noise lines, is increased daily by ten noise lines, starting at ten noise lines per presentation (twelve noise line in the

non stimulus presentation) until the performance of all observers is reduced to near chance levels. The experiment is then repeated starting at the highest noise density and decreasing the mask density by ten noise line per day until the initial noise density is reached. Scores are pooled for all equivalent visual masking noise levels.

Stimulus Forms

The stimulus forms consist of three different types of regularly spaced dotted lines. Each line consisted of seven dots that varied in interdot distance. All interdot distances are the same in any given line. The distance between the dots may be 8.76, 17.4 or 25.8 mins. of visual angle respectively. The three lines, therefore, subtend 1.02, 2.04 and 3.06 degs. of visual angle respectively. The middle dot in each line occupied the center position of the cubical space. Each of these three stimulus lines could be rotated around either the X, Y, or Z axis in 5 deg. steps (± 20, ± 15, ± 5, 0), all constrained to an imaginary plane passing through the center of the cube. The distance between the dots of the noise lines is held to a constant 17.4 min. of visual angle. The noise lines, therefore, all subtended 1.16 deg of visual angle.

Apparatus

The stereoscopic stimuli used in this experiment are generated by a hybrid computer system consisting of a Cromemco System 3 digital microcomputer and a subsystem of Optical Electronics Inc. analog computer components. The microcomputer generated and stored the X, Y and Z coordinates specifying the

location in space of each dot within the apparent cubical space. The analog subsystem transforms these coordinates into two sets of two-dimensional coordinates (one for each half of the oscilloscope) each having the proper disparity, perspective and separation needed to project a pair of haploscopic images. The digital to analog converter used in this system was a California Data Corporation DA-100, a four channel system. Three channels are used to convert the X, Y and Z dimensions while the fourth is used to regulate the spatial separation between the left and right images drawn on the oscilloscope. The disparity and perspective of the two images were adjusted with external regulating potentionmeters and are held constant throughout the experiment.

The stimuli are displayed on a Hewlett-Packard model 1311B large screen CRT treated with P-24 phosphor. The field of view presented to each eye on the two halves of the oscillioscope is shielded by an opaque screen through which a pair of 5.4 deg X 5.4 degree apertures (one for each eye) had been cut. This shielding is attached directly to the face of the oscilliscope. The viewing distance from the observers cornea to the CRT was 31.75 cm. A piece of black painted plywood ran from the chin rest to the front of the CRT to divide the two eye's viewing fields.

EXPERIMENT 1

In recent years several experiments have shown that the introduction of apparent depth into a visual masking experiment reduces the masking effect (Fox, 1981; Gogel and Mershon 1969; Mershon, 1972). It appears that the introduction of apparent depth increases the signal to noise ratio between the

mask and stimulus by spreading the mask into a larger volume and thus reducing its' effective density and increasing its' effective signal to noise ratio. Experiments 1 and 2 compare the detection performance of observers in a monocular (Experiment 1) and a steroscopic (Experiment 2) environment. It is expected that the observer's performance will be higher in the steroscopic environment than in the moncular environment at comparable noise levels.

Specific Method

Each of the three stimulus lines was rotated around the Z axis in 5 degree steps (±15, ±10, ±5, 0) starting from a horizontal position as shown in Fig. 11. All of the stimulus forms (3 stimulus lines x 7 orientations = 21 forms) were centered in a frontal-parallel plane placed at the middle depth of the cube. All masking lines were kept horizontal. In Experiment 1 a black patch was placed over the right viewing prism blocking visual input to the right eye. Masking densities of 10, 20, 30, 40, 50, 60, and 70 noise lines in each presentation were used.

Results and Discussion

The results of Experiment 1 are shown in Figs. 1 and 2 and in Tab. 1. In Fig. 1 the percentage of the total number of correctly detected stimuli is plotted as a function of the stimulus lines orientation. In Fig. 2 the percentage of the total number of correctly detected stimuli is plotted as a function of the interdot distance of the stimulus line. In both graphs this procedure produces a family of curves that are parametric with the number of dotted noise lines used. As can be seen from the graph in Fig. 1, as the angle of the stimulus line is increased in either a plus or minus direction away from the frontal-parallel position, there is an increase in the observer's performance. The curves in this family are all positively accelerated and asymptote at approximately 10 degrees

(plus or minus). In contrast, the curves in Fig. 2 display a mixture of three different response types. At the lowest noise density level the curve is positively accelerated showing improved detection performance with an increase in interdot spacing. At the next noise level (20 noise lines per presentation) the curve appears to be flat. The remaining noise level curves all show negatively accelerating curves depicting increased detection performance with decreases in dot spacing. None of the curves appears to reach an asymptote.

Table 1 presents the Anova analysis for orientation, interdot spacing and their interaction. There were significant effects at all noise densities for both orientation and interdot spacing with one exeception. The one exception is the the effect of interdot spacing at a noise density of 20 noise lines per presentation.

EXPERIMENT 2

Experiment 2 is identical to Experiment 1 with the single exception that observers view the presentations steroscopically. As noted earlier, it is expected that the observer's performance will be higher in the stereoscopic than in the monocular situation at comparable noise levels since the introduction of apparent depth in some manner decreases the effectiveness of the mask. This decreased effectiveness may be the result of the masking lines being spread into a larger volume thus effectively increasing the effective signal-to-noise ratio between stimulus and mask. The performance of observers in Experiment 2 will also be contrasted with the results of later experiments to allow comparison of the effects of rotation of the stimulus around different axes.

Results and Disscussion

The results of Experiment 2 are shown in Figs. 3, 4 and Tab. 2. In Fig. 3 the percentage of the total number of correctly detected stimuli is plotted as a function of the orientation of the stimulus line. In Fig. 2 the total number of correctly detected stimuli are plotted as function of the interdot distance. Again, in both graphs this procedure produces a family of curves that are parametric with the number of dotted noise lines used. The graph in Fig. 3 again shows that as the angle of the stimulus line is increased away from the frontal-parallel position observer's detection performance increases. The curves are all positively accelerated and asymptote at approximately 10 degrees (plus or minus). As can be seen by visual inspection, increasing the number of noise lines *fails to result in a degradation in the observer's performance* when the stimulus line has been rotated 10 degrees or more. The graph in Fig. 4 displaying the effect of interdot spacing again shows a mixture of three different response curves. At the lowest two noise levels (10 and 20 dotted noise lines per presentation, respectively) the curves are positively accelerated indicating increased performance as the dot spacing is increased. The next lowest noise level curve (30 noise lines per presentation) appears flat, while the remaining curves all show negatively accelerating curves indicating increased performance as dot spacing is decreased.

Table 2 presents an Anova analysis for orientation, interdot spacing and their interaction. Again, both orientation and interdot spacing display significant effects at almost all noise levels. The two exceptions are the cases in which 20 and 30 noise lines are used; each of these curves produces flat curves in Fig. 4.

A comparsion between the results of Experiments 1 and 2 shows two interesting results. The first is that the observer's performance is better in the

steroscopic environment than in the monocular environment. This outcome provides additional support for the hypothesis that the introduction of apparent depth in a visual masking experiment reduces the effectiveness of the mask by increasing the effective signal-to-noise ratio. In the steroscopic environment increases in the angle of the stimulus line, around the Z axis away from the frontal-parallel postion, is a more effective cue for correct detection. This is evidenced by the high level of performance. Scores stay in the 90% correct range even at the highest noise levels utilized. This may be contrasted to performance levels in the monocular environment where performance levels were lower (15%) at the highest noise densities even when the stimulus line had been rotated 10 degrees or more around the Z axis. It is also important to note that in Fig. 3 that an additional ten noise lines per presentation failed to substantially reduce down observer's performance.

A second interesting result suggests something about the mechanism(s) responsible for detecting dotted stimuli. In both Experiments 1 and 2, the graphs showing the effect of interdot spacing are composed of three different response curve types. These different types emerge at different noise densities. At low noise densities increases in dot spacing improved detection performance. On the other hand at higher noise densities decreases in dot spacing improved detection performance. Additionally, there is an intermediate range of noise levels at which the effect of dot spacing is not significant at all. These results suggest either that there is one mechanism using two different processing algorithms or that there are two different mechanisms involved in detecting dotted stimuli.

We must also consider other organizational properties of both the noise line and the three stimulus lines in attempting to explain these results. The dotted noise line always subtended 1.16 degrees of visual angle. The three stimulus

lines, however, subtend 1.02, 2.04, and 3.06 degress of visual angle. Therefore, both the noise line and the small stimulus line appear approximately the same length on the retina (though the small stimulus line has more dots, seven compared to four, than the noise line). One possibility is that at low noise densities this dot detection mechanism works by looking for the longest line. At higher noise densities this mechanism may shift strategies and look for the brightest line (which would be the smallest stimulus line).

The results of these two experiments are similiar to the results of studies reported by Sekuler (1965) and Parlee (1968). It seems likely, since lateral inhibition can not explain the masking effect here, that at least some of the effect they attributed to a lateral inhibitory mechanism in the retina may actually be due to a more central cognitive mechanism. Experiment 2, in particular, is similiar to their experiments in that the stimulus line and the masking lines are both horizontal and that the stimulus lines are rotated around the Z axis away from this horizontal position. In both their experiments, and the ones reported here, the masking effect diminishes sharply as the stimulus line is rotated past 15 degrees. Yet, in the present study it is unlikely that there is any masking effect that can be attributed to a lateral inhibitory mechanism in the retina for the reasons cited previously. This suggest a more central basis for the masking effects reported in all of these experiments.

EXPERIMENT 3

As mentioned earlier, Uttal (1975; 1983) reported that observers are insensitive to changes in the orientation of dotted stimulus lines. These results come from a limited study of the effect of orientation. In Uttal's two earlier experiments only four different orientations were tested in each experiment. Additionally the changes in orientation in Uttal's (1975) work were all rotations

around one axis; in Uttal's (1983) later work the changes in orientation were around two axes, but the changes were very symmetrical. Experiment 3 is designed to further test observer's performance in detecting orientation differences in dotted stimuli. This experiment will test the dot detection mechanism's sensitivity to perceive changes in orientation of the stimulus lines around the Y axis. These results will be contrasted with earlier results to see if this mechanism varies in its sensitivity to detect orientation differences between the stimulus and noise lines in a way that is dependent upon the dimension in which these orientation differences occur. If this mechanism's sensitivity does vary with the dimension about which the stimulus are rotated it would be suggestive that changes in some dimensions are more ecologically important for form perception than changes in others.

Specific Method

In this experiment each of the three stimulus lines described was rotated to a new stable position around the Y axis in 5 degree steps ($\pm$ 20, $\pm$ 15, $\pm$ 10, $\pm$ 5 and 0) starting from a horizontal position. All of the stimulus forms (3 lines x 9 orientations = 27 forms) were centered in a horizontal plane placed at the center of the viewing cube. All masking lines were always kept horizontal. Masking density of 10, 20, 30, 40, 50, 60, and 70 noise lines in each presentation were used on successive days.

Results and Discussion

The results of Experiment 3 are shown in Figs. 5, 6 and Tab. 3. In Fig. 5 the percentage of the total number of correctly detected stimuli is plotted as a function of the stimulus lines orientation. In Fig. 6 the total number of correctly detected stimuli is plotted as function of the interdot distance. In both

graphs this procedure produces a family of curves that are parametric with the number of dotted noise lines. As can be seen in the graph in Fig. 5, there does not appear to be any systematic effect due to the rotation of the stimulus line around the Y axis. This result is in sharp contrast to the results of Experiments 1 and 2 in which rotation about the Z axis played a strong role in influencing detection performance. The graph in Fig. 6, depicting the effects of interdot spacing, displays a mixture of two types of response curves. At the lowest noise density (10 lines per presentation) the curve is flat. At all succeeding noise levels the curves are L shaped showing that the stimulus lines with the smallest interdot differences are detected best while those with intermediate and larger spacing less well. These results, in contrast to the orientation results, are similiar to the results of Experiments 1 and 2 suggesting that the detection mechanism varies in its sensitivty to detect orientation differences in a way that is dependent upon the dimension in which these changes occur, but not in the strategies or algorithms it uses to detect or construct the the perceived form.

Table 3 presents the Anova analysis for orientation, interdot spacing and their interaction. There are no significant effects for orientation and interaction. There are significant effects for interdot spacing at most noise levels. In this regard the results of the Anova reflect the appearance of the curves displayed in Fig. 6. Interdot spacing did not produce any performance effect at the lowest noise densities and increasingly significantly effects at higher noise densities.

EXPERIMENT 4

It is apparent from the results of the first three experiments that the visual space perceived by the dot detection mechanism is not isotropic. The results from Experiment 3 (Fig. 5; Tab. 3) of the effect of rotating the stimulus

stimulus line around the Y axis away from the fronto-parallel orientation of the noise line are in sharp contrast to the results of Experiment 2 (Fig. 3; Tab. 2) that demonstrated the effect of rotating the stimulus line around the Z axis. Experiment 4 further tests this mechanism's ability to detect orientation differences by testing its ability to detect stimulus lines that have been rotated around the Z axis away from an oblique starting position shown in Fig.11. The noise lines in this experiment are parallel to this oblique position. The results of this experiment will allow comparsion of the relative effects of rotation within one dimension since in this experiment, as in Experiments 1 and 2, the stimuli are rotated around the Z axis.

Specific Method

Each of the three stimulus lines was rotated around the Z axis in 5 degree steps (±20, ±15, ±10, ±5, 0) starting from an oblique left position (Fig. 11). Each of the stimulus forms (3 stimulus lines x 9 orientations = 27 forms) were centered in a horizontal plane placed at the middle depth of the cube. The masking noise lines were always presented parallel to the non-rotated oblique stimulus line. Masking density of 10, 20, 30, 40, 50, 60, 70 and 80 noise lines in each presentation were used on successive days.

Results and Discussion

The results of Experiment 4 are shown in Figs. 7, 8 and in Tab. 4. In Fig. 7 the percentage of the total number of correctly detected stimuli is plotted as a function of the stimulus line orientation. In Fig. 8 the percentage of the total number of correctly detected stimuli is plotted as a function of the interdot distance. In both graphs this procedure produces a family of curves that are parametric with the number of dotted noise lines used. As can be seen from Fig.

7, increasing the angle of the stimulus line, in either a plus or minus direction away from the oblique noise lines, increases the observer's performance. This family of curves are all positively accelerated and appear to asymptote at approximately ± 20 degrees. In contrast, the curves in Fig. 8 displays a mixture of three different response types. At the lowest noise density noise level (10 noise lines per presentation) the curve is flat. At the next three noise levels (20, 30 and 40 noise lines per presentation respectively) the curves are L shaped, reaching an asymptote at the intermediate interdot distance difference. The remaining noise level (50, 60, 70, and 80 noise lines per presentation) the curves are all negatively accelerated indicating increased detection performance as dot spacing is decreased. A visual comparision of the results of Experiment 2 (Fig. 3) and of Experiment 4 (Fig. 7) suggest that even when rotation is restricted to the same axis, the Z axis, there is a difference in detection performance dependent upon the orientation of the noise lines. In Experiment 2 the noise lines are horizontal; in Experiment 4 the noise lines have been rotated to +45 degrees. As can be seen in Figs. 3 and 7 the dot detection mechanism appears to be more sensitively tuned to detect orientation changes of horizontal stimulus lines than to detect orientation changes of oblique stimulus lines. That is, performance scores are consistently better when the noise lines are horizontal than when they are oblique even when the respective orientation difference, between the stimulus and the noise are the same. It should also be noted that in Fig. 3 the curves appear to asymptote at 10 degrees of stimulus line rotation, whereas in Fig. 7 the curves appear to asymptote at 20 degrees.

Finally, Fig. 3 shows that increases in masking noise densities failed to drive down the detection scores of the stimulus lines after they had been rotated 10 degrees; whereas in Experiment 4 increases in noise densities continued to drive down the detection score over the total range of noise densities utilized.

These results suggest that the differences between the results of Uttal (1975; 1983) and the results of those researchers summarized by Appelle (1972) were due to the nature of the experimental paradigms used and not due to the nature of the stimuli used.

Table 4 presents the Anova analysis for orientation, interdot spacing and their interaction. There are significant effects for orientation at all noise densities. There are significant effects for the role of stimulus line interdot spacing only at intermediate (30 lines per presentation) and higher noise levels.

EXPERIMENT 5

Experiments 1 through 4 have demonstrated that the effect of rotation of stimulus lines on detection performance is effected both by the axis about which the rotation occurs and the orientation of the noise lines. Experiment 5 now asks what is the effect on this kind of task when the masking lines are systematically rotated rather than the stimulus lines. Experiment 5 explores this possibility by always presenting the three stimulus lines in a horizontal orientation but rotating the noise lines to new orientations around the Z axis in random order in successive trials. Since there are always more noise lines than the single stimulus line (by a minium factor of 10 to 1) in any presentation the visual system may tend to perceive the orientation of the noise lines as the horizontal. Evidence that this is the case has been presented by Attneave and Olson (1967) and Attneave and Reid (1968).

The particular question asked here is will the results of this experiment resemble those of Experiment 2 in which the dot detection mechanism showed excellent abilty to detect orientation differences between a stimulus and horizontal noise lines or will they resemble those of Experiment 4 in which the

dot detection mechanism displayed poorer performance in detecting orientation differences between a stimulus and oblique noise lines. If the masking effect is due to a relatively simple peripheral neural mechanism involved in the extraction of information then the results should resemble these of Experiment 2. Alternately, if this mechanism is a relatively more complex central neural network capable of using multiple strategies then the results should resemble those of Experiment 4. In the latter case the dot detection mechanism may first attempt to determine the true horizon and this process may interfer with detection of the stimulus.

Specific Method

Each of the three stimulus lines is presented in a horizontal position centered in a frontol-parallel plane placed at the middle of the cube. In each trial the noise lines were all rotated around the Z axis to the same single randomly chosen orientation. The orientations of the noise lines used in successive trials were ±20, ±15, ±10, ±5 and 0 degrees all relative to the horizontal stimulus lines. Masking line densities of 10, 20, 30, 40, 50, 60, 70 and 80 lines in each presentation were used on successive days.

Results and Disscusion

The results of Experiment 5 are shown in Figs. 9, 10 and in Tab. 5. In Fig. 9 the percentage of the total number of correctly detected stimuli is plotted as a function of the noise line orientation. In Fig. 10 the total number of correctly detected stimuli is plotted as a function of the interdot distance in the stimulus line. In both graphs this procedure produces a family of curves that are

parametric with the number of noise dots used. The graph in Fig. 9 shows modest increases in observer's performance with increases in the angle of rotation of the noise indicating a reduction in the masking efficieny. The curves are all positively accelerated. Figure 10 displays an L shaped family of curves depicting the role of interdot spacing in the stimulus lines. At low noise levels (10 noise lines per presentation) all stimulus lines are detected equally well. Increasing noise density lowers detection performance for the the intermediate and longer stimulus lines.

Table 5 presents the Anova analysis for orientation, interdot spacing and their interaction. There are significant effects for orientation at most noise levels, the one exeception being the condition with 20 noise lines per presention. There are significant effects for interdot spacing at all noise levels, but none for the interactions between the two factors.

The results of Experiment 5 (Figs. 9 and 10; Tab. 5) are clearly different from those in Experiment 2 (Figs. 3 and 4; Tab. 2) suggesting that the mechanism(s) involved in detecting the dotted stimuli is a very complex neural network which uses multiple strategies dependenting upon the conditions of the visual task. In Experiment 5 the observers had to detect three horizontal lines while the noise lines were rotated to various nonparallel angles. In contrast, in Experiment 2 the noise lines were held in a constant horizontal orientation while the stimulus lines were rotated. The divergent results between these two experiments suggest that the introduction of what may be a false horizontal triggers some type of additional processing that interferes with the detection of the stimuli and thus degrades performence. It is interesting to note that in Experiment 5 (Fig. 9) adding noise drove down the observer's performance for all orientations. This outcome can be contrasted to both Experiments 2 and 4 (Figs. 3 and 7) where once a given maximum angle of rotational difference between

stimulus and noise lines had been achieved additional noise fails to drive down observer's performance. This suggests that the decrement in performance does not result from an insensitivity to orientation changes but, rather from some type of additional processing which appears to take precedence over or interfers with detection of the stimulus.

GENERAL DISCUSSION

These experiments explored a visual mechanism involved in the detection of single dotted stimuli masked by multiple dotted noise lines. In general the results of the five experiments conducted show that this mechanism varies in its sensitivity to detect orientational differences between stimulus and noise lines in a manner that is dependent upon the axis about which rotations occur as well as the orientation of the stimulus and noise lines. Rotation of the stimulus line around the Z axis is more effective in separating signal from noise than is rotation around the Y axis. When stimulus lines are rotated around the Z axis, orientation differences between horizontal stimulus and noise lines serve as better cues for detection than orientation differences between oblique stimulus and noise lines. These results suggest that some types of rotational differences are more ecologically important than others in spatial form perception.

The experiments reported here suggest that differences in the results obtained by Uttal and those researchers summarized by Appelle (1972) are due to nature of the experimental methods used and not to the nature of the stimuli used (dotted lines verus solid lines). Uttal (1975; 1983) suggested that the visual space perceived by the dot detection mechanism is isotropic. The results reported here indicate that this is true only when stimulus forms are masked by random patterns of dots. The addition of structure, that is, linear organization,

to the mask changes the experimental results. This change in experimental paradigm appears to make the task more of a discrimination task. Under these new conditions the visual space perceived by the dot detection mechanism is not isotropic as discussed above.

The differences in the results of Experiments 2, 3, and 4 in the present study seem to rule out peripheral lateral inhibition as the mechanism responsible for the masking effect. If a retinal lateral inhibitory mechanism is responsible, the effect of the orientation differences in Experiments 2 and 4, in which the stimulus lines were rotated around the Z axis should be identical. Clearly this is not the case. Additionally, one would expect the effect of orientation differences to be a poor cue for detection in Experiment 3 since the orientation difference is around the Y axis. This was the case, but, a closer examination of the results, specifically of the role of interdot spacing between the dots of the stimulus lines on detection performance, also suggests that retinal lateral inhibition is not a satisfactory explantation of the phenomena. If retinal lateral inhibition is the cause of the masking effect then the lines with the largest interdot distance would have been detected best since the effect of lateral inhibition falls off as the distance increases. The reverse is actually true however, the lines with the smallest interdot distance are detected best. These results suggest that the masking effect seen in these experiments probably resulted from an overloading of a relatively complex neural mechanism's ability to extract information from the visual environment. This neural mechanism must exist at an intermediate, or higher, level of the nervous system since perpheral lateral inhibition has been ruled out.

Two other sets of data shed some light on the details of the visual mechanism that may be involved in this task. The first one is obtained in Experiment 5. The rotation of the noise line to other than an horizontal

orientation interfered with the detection of the stimulus line. One interpetation of these results is that this mechanism is set up to perceive ecologically important information and that there may be a hierarchy of importance associated with the extraction of information from the visual environment. In accord with this interpetation, the visual processing involved in determining the apparent horizon takes precedence over the detection of forms in the visual environment.

The final result of special interest is that the role of local geometry, as a cue for detection, reverses as noise density increases when orientation changes between the stimulus and noise lines are made around the Z axis. At low noise densities the lines with the largest interdot distance are perceived best. As noise density is increased a point is reached at which all three lines are perceived equally well. Further increases result in the lines with the smallest interdot distances being perceived best. These results both confirm and extend the earlier work reported by French (1953) and Uttal (1970; 1975; 1983). In both French's and Uttal's earlier work targets with the smallest interdot distances were detected best. The results of these experiments, however, have shown that this is true only at moderate and higher densities of visual noise. At low densities of visual noise targets with the largest interdot distances are detected best. It is important to note that this effect only resulted from changes made around the Z axis, not from changes made around the Y axis.

What type of mechanism could account for these results? One possible model is a mechanism characterized as a variable aperture attentional process (Bergen and Julesz, 1983). The variable attentional process model allows the dot detection mechanism to vary the size of the "aperture" of the region being scanned. In the experiments reported here the aperture would be controlled by the brightness of the visual field. At low noise densities, and hence low

brightness of the visual field, the aperture is set wide open. The dot detection mechanism scans the whole field simultaneously. *Under these conditions the* longest line, the one with the largest interdot distance, should be easiest to detect because it differs maximally from all the other lines, both target and noise. Its' length stands out and serves as a cue to guide the mechanism in detection. As the number of noise lines increases the brightness of the visual field also increases resulting in a closing down of the attentional aperture. The mechanism now must scan multiple, overlapping areas looking for the target line. Under these conditions the role of interdot distance diminishes as a cue for detection. Further increases in the density of the noise result in a further closing down of the attentional aperture. The mechanism now has even more areas which must be scanned to find the target. But, under these conditions the mechanism now has a cue to guide it in its search pattern. Some areas should appear brighter than surrounding areas due to more dots being present per unit area in those regions. Under these conditions the mechanism first scans the whole environment looking for the brightest regions. There would be multiple regions of increased brightness because one region should have the small stimulus line (which has more dots per unit area than the other stimulus lines) and because it is also possible for noise lines to overlap in space. The dot detection mechanism would then focus its search in these regions. By scanning these bright regions the mechanism identifies the stimulus form.

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Figure Captions

Figure 1. Graph showing the effect of orientation differences between stimulus and noise lines in Experiment 1. Increases in orientation differences improve observer's performance.

Figure 2. Graph showing the effect of interdot spacing in Experiment 1. Graph shows three different response curves indicating that the role of local geometry reverses as a function of noise density.

Figure 3. Graph showing the effect of orientation differences between stimulus and noise lines in Experiment 2. Increases in orientation differences improve observer's performance.

Figure 4. Graph showing the effect of interdot spacing in Experiment 2. Graph shows three different response curves indicating that the role of local geometry reverses as a function of noise density.

Figure 5. Graph showing the effect of orientation differences between stimulus and noise lines in Experiment 3. Increases in orientation differences due not improve observer's performance.

Figure 6. Graph showing the effect of interdot spacing in Experiment 3. Graph shows two different response curves indicating that the role of local geometry changes as a function of noise density.

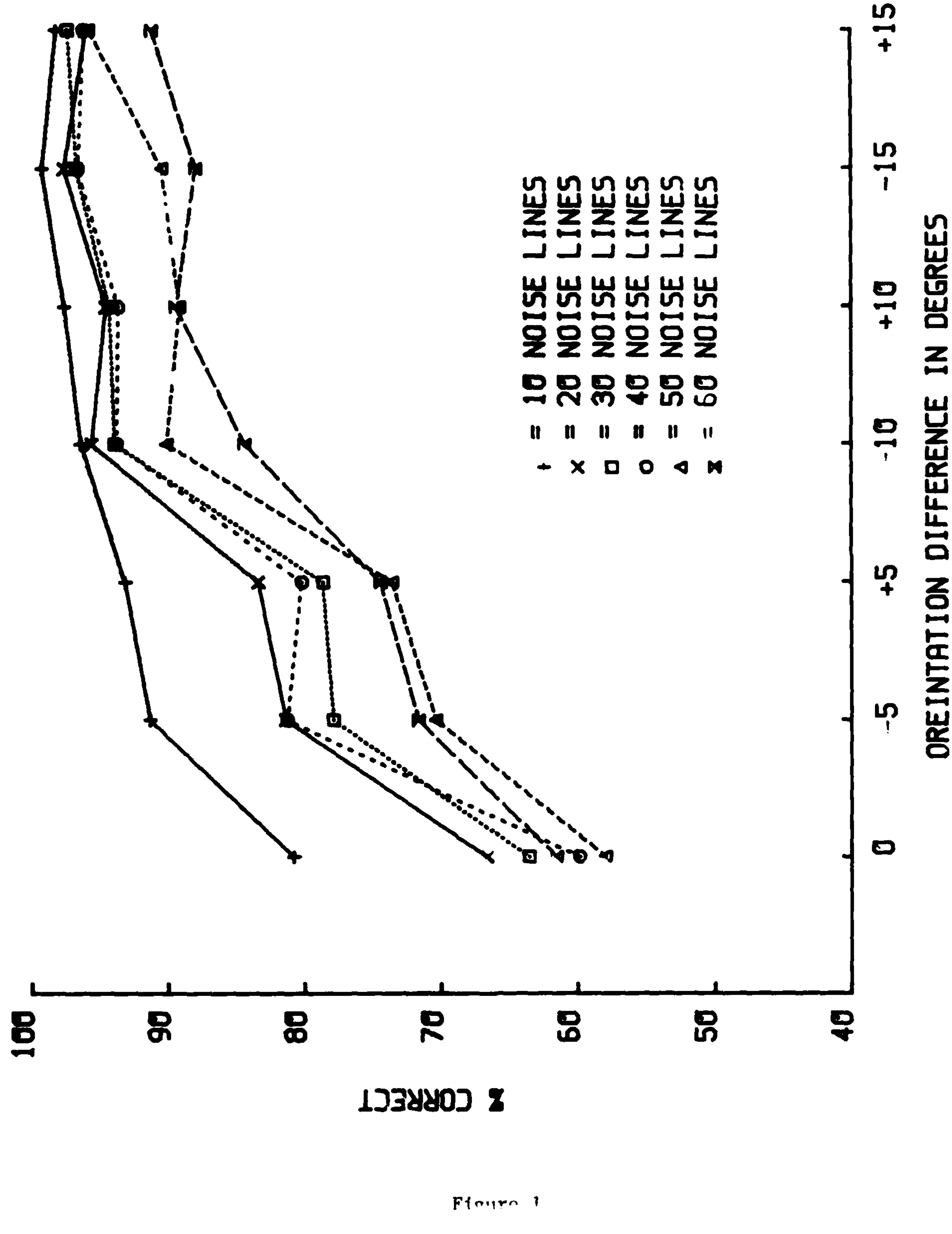
Figure 7. Graph showing the effect of orientation differences between stimulus and noise lines in Experiment 4. Increases in orientation differences improve observer's performance.

Figure 8. Graph showing the effect of interdot spacing in Experiment 4. Graph shows two different response curves indicating that the role of local geometry changes as a function of noise density.

Figure 9. Graph showing the effect of orientation differences between stimulus and noise lines in Experiment 5. Graph shows slight improvement in observer's performance as orientation differences increase.

Figure 10. Graph showing the effect of interdot spacing in Experiment 5. Graph shows two different response curves indicating that the role of local geometry changes as a function of noise density.

Figure 11. The stimulus forms used in these experiments. A) The stimulus form with the smallest interdot distance in the horizontal position. B) The stimulus form with the intermediate interdot distance in the horizontal position. C) The stimulus form with the largest interdot distance in the horizontal position. D) The stimulus form with the intermediate interdot difference in the oblique position.



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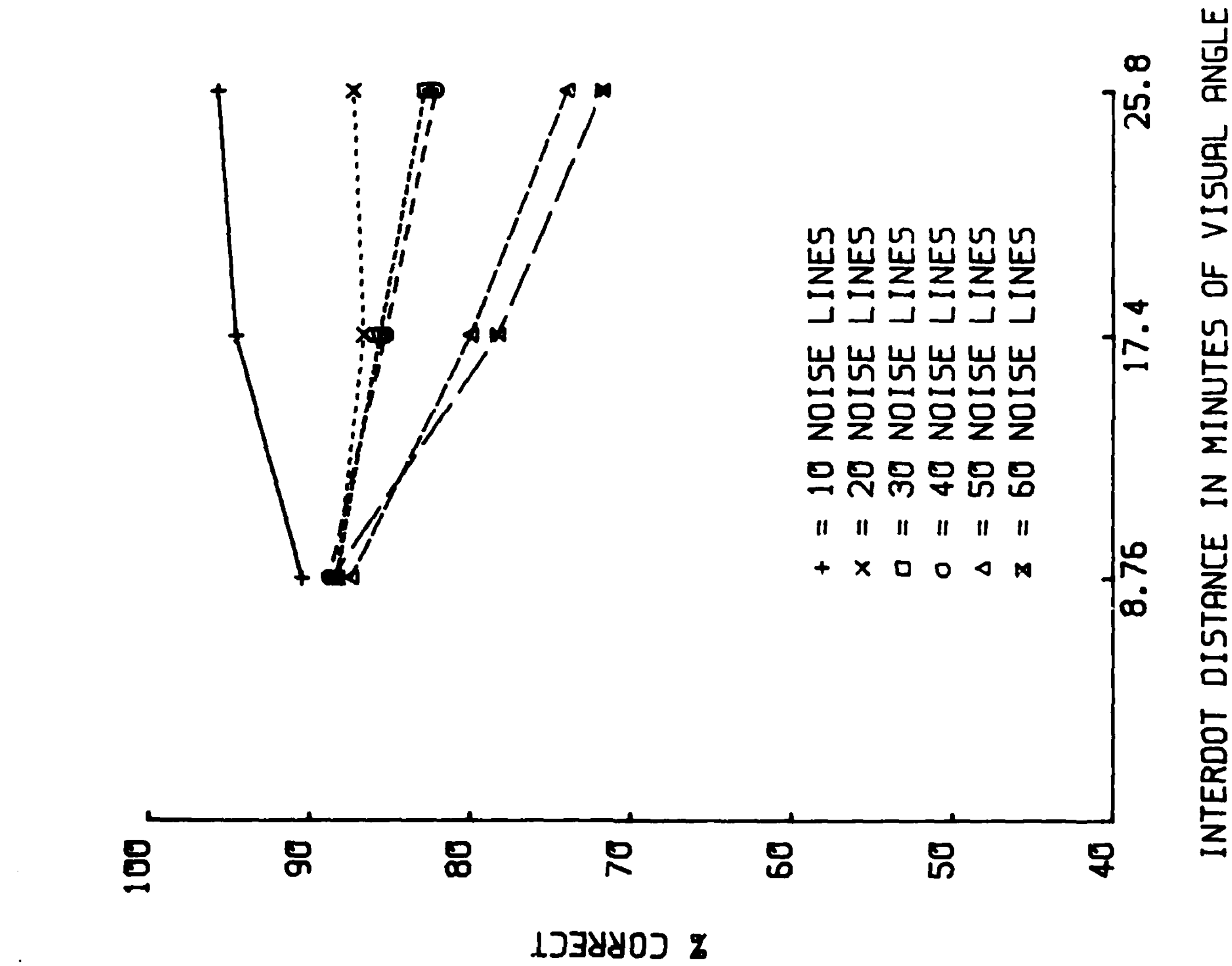
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Figure 2

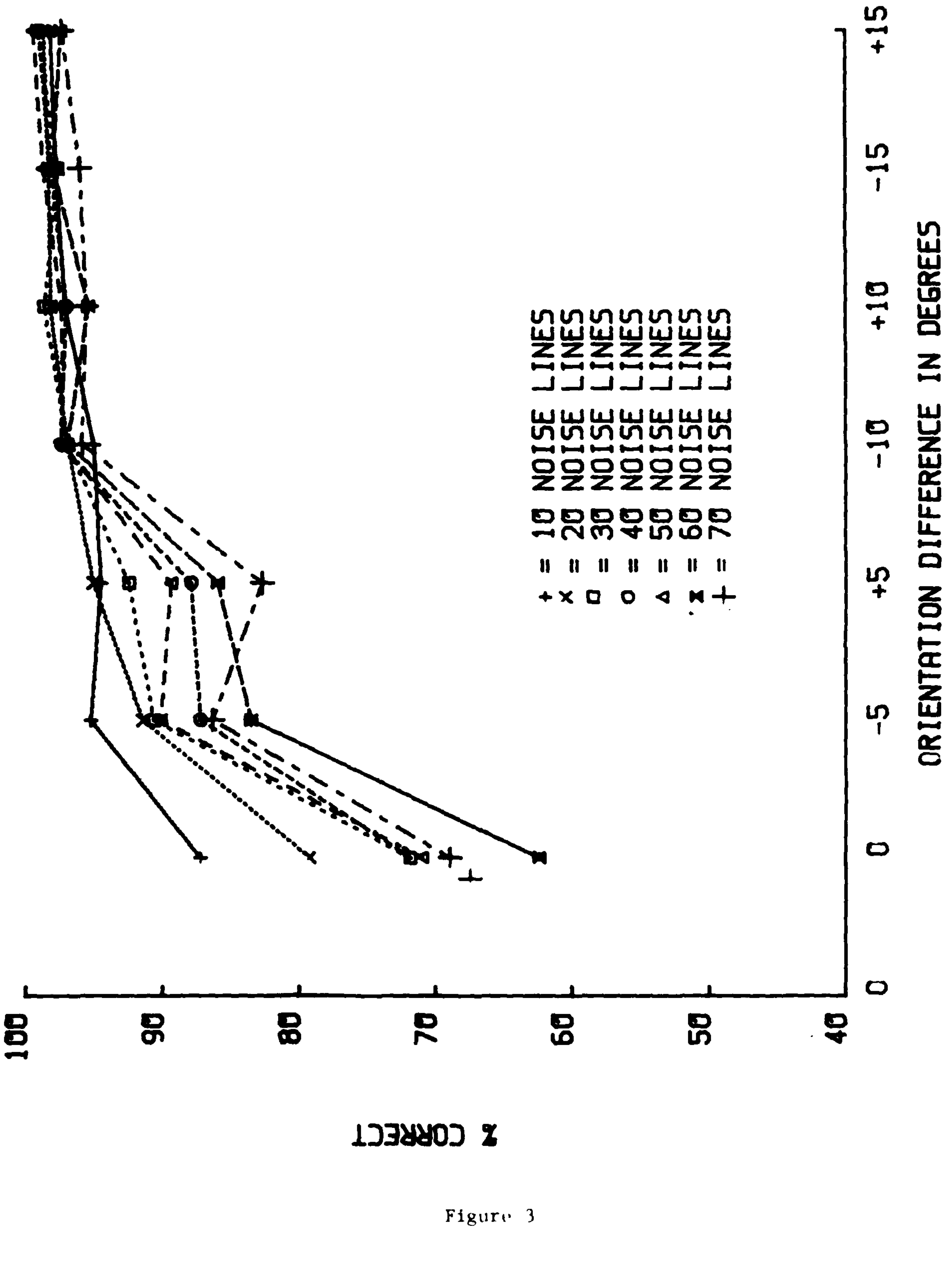
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Figure 3

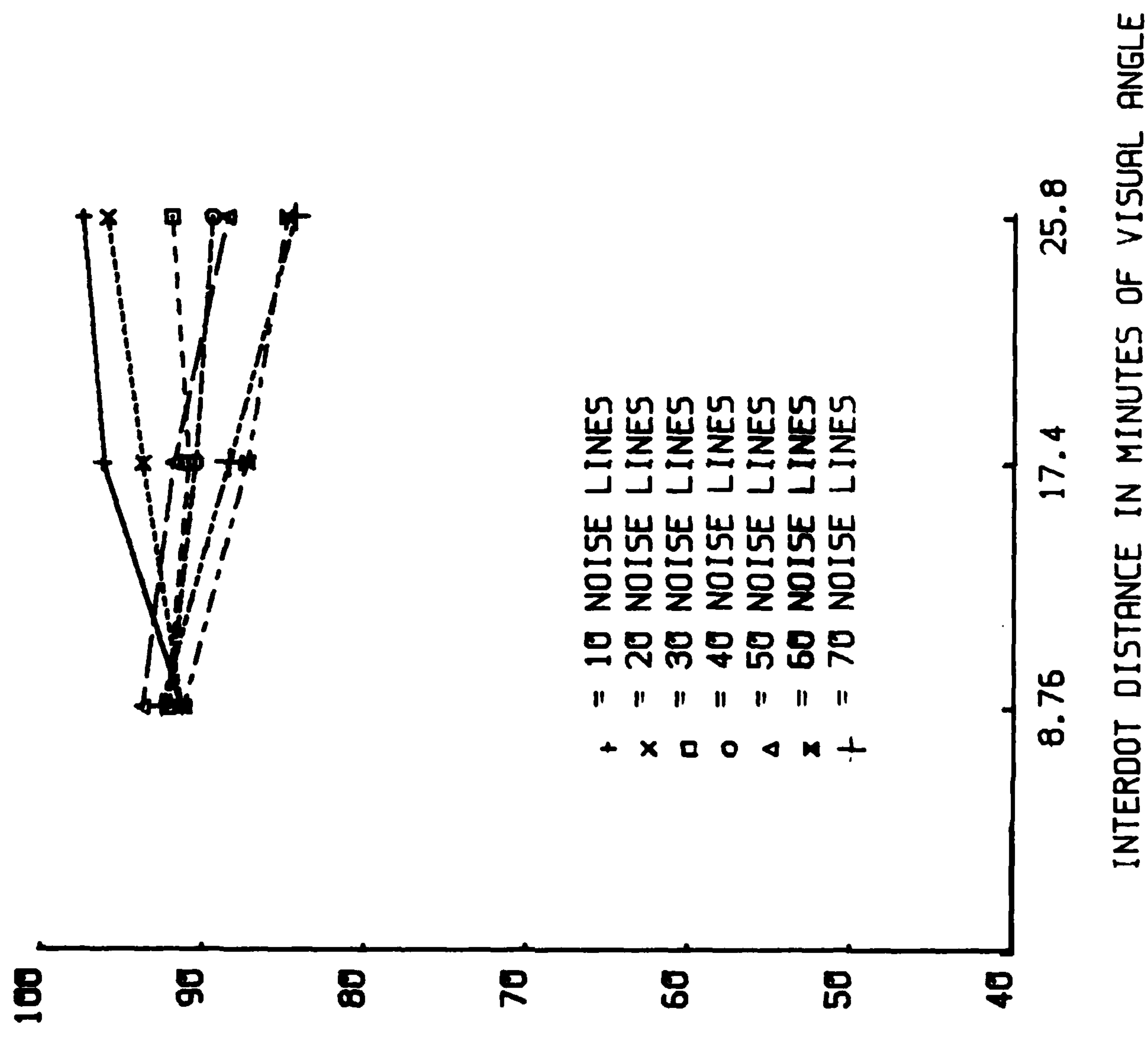
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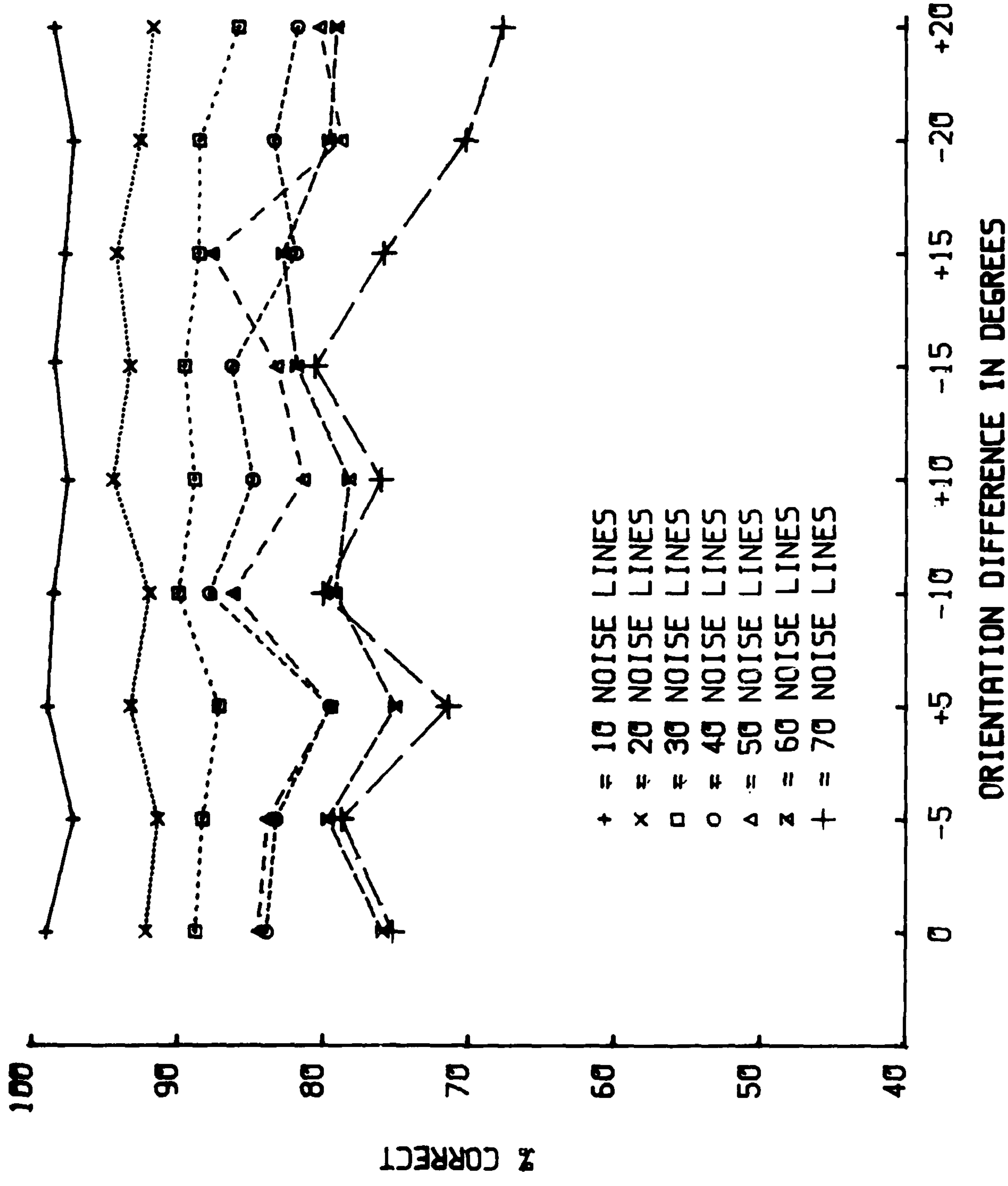
Figure 4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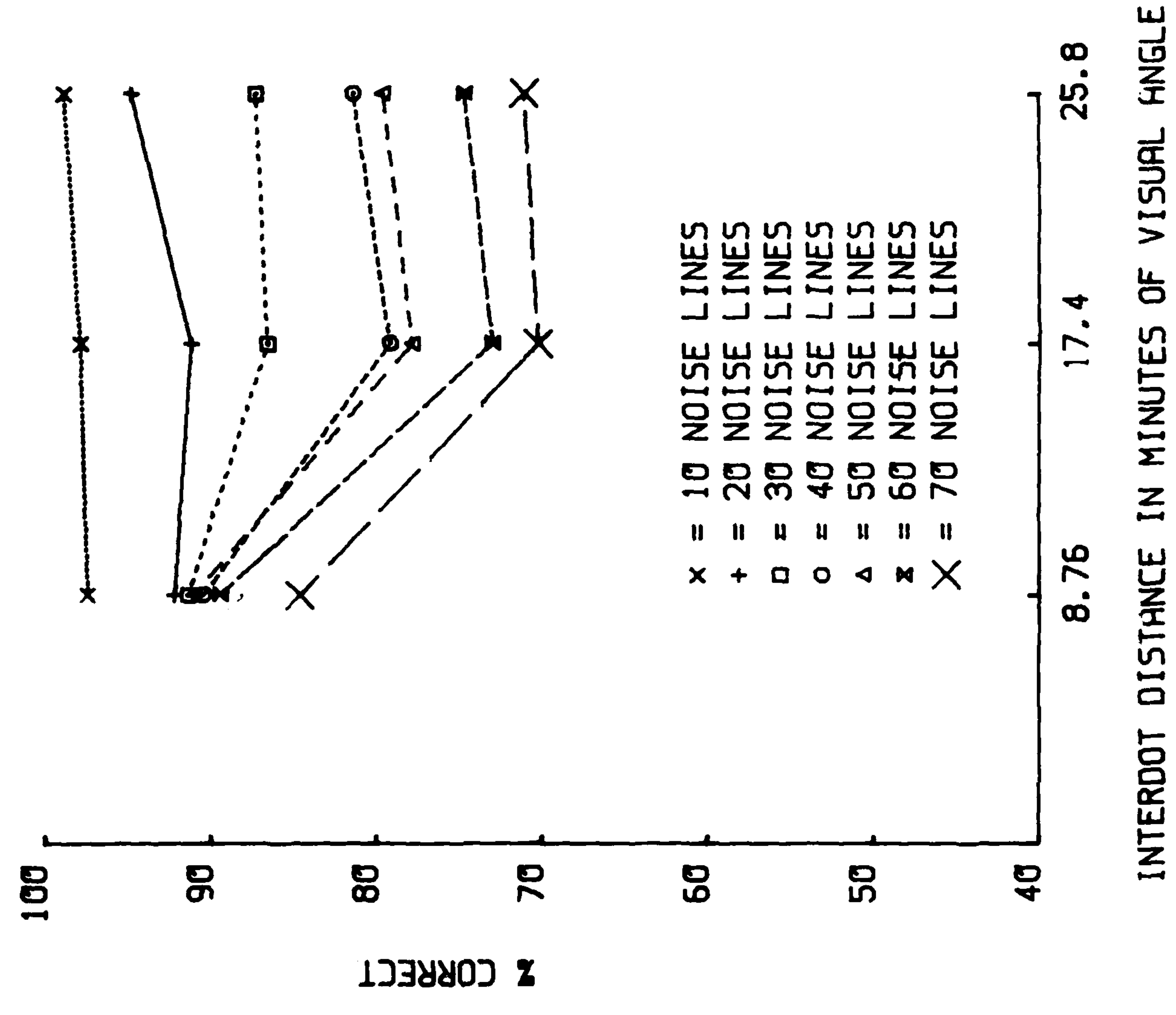
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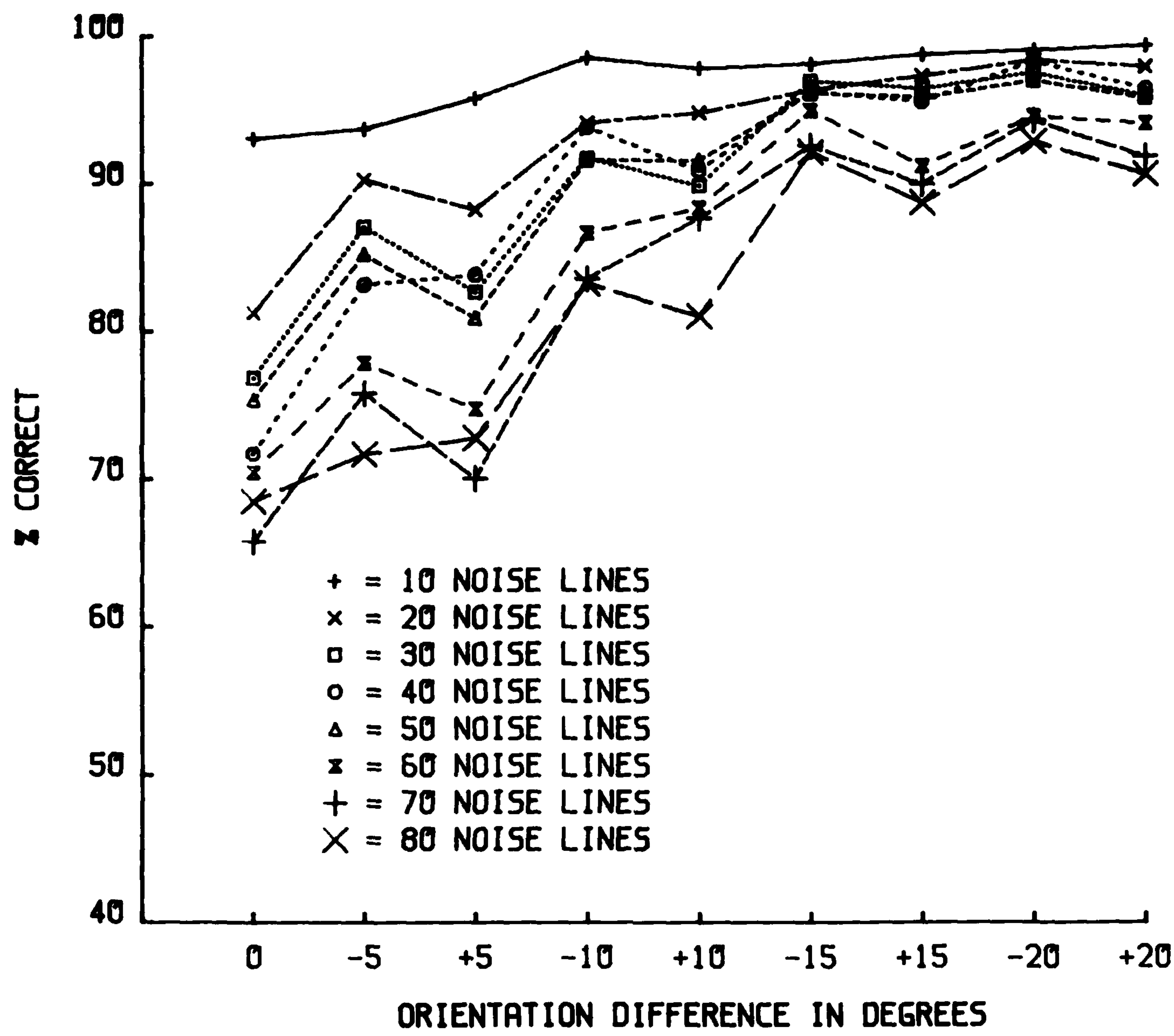
Figure 6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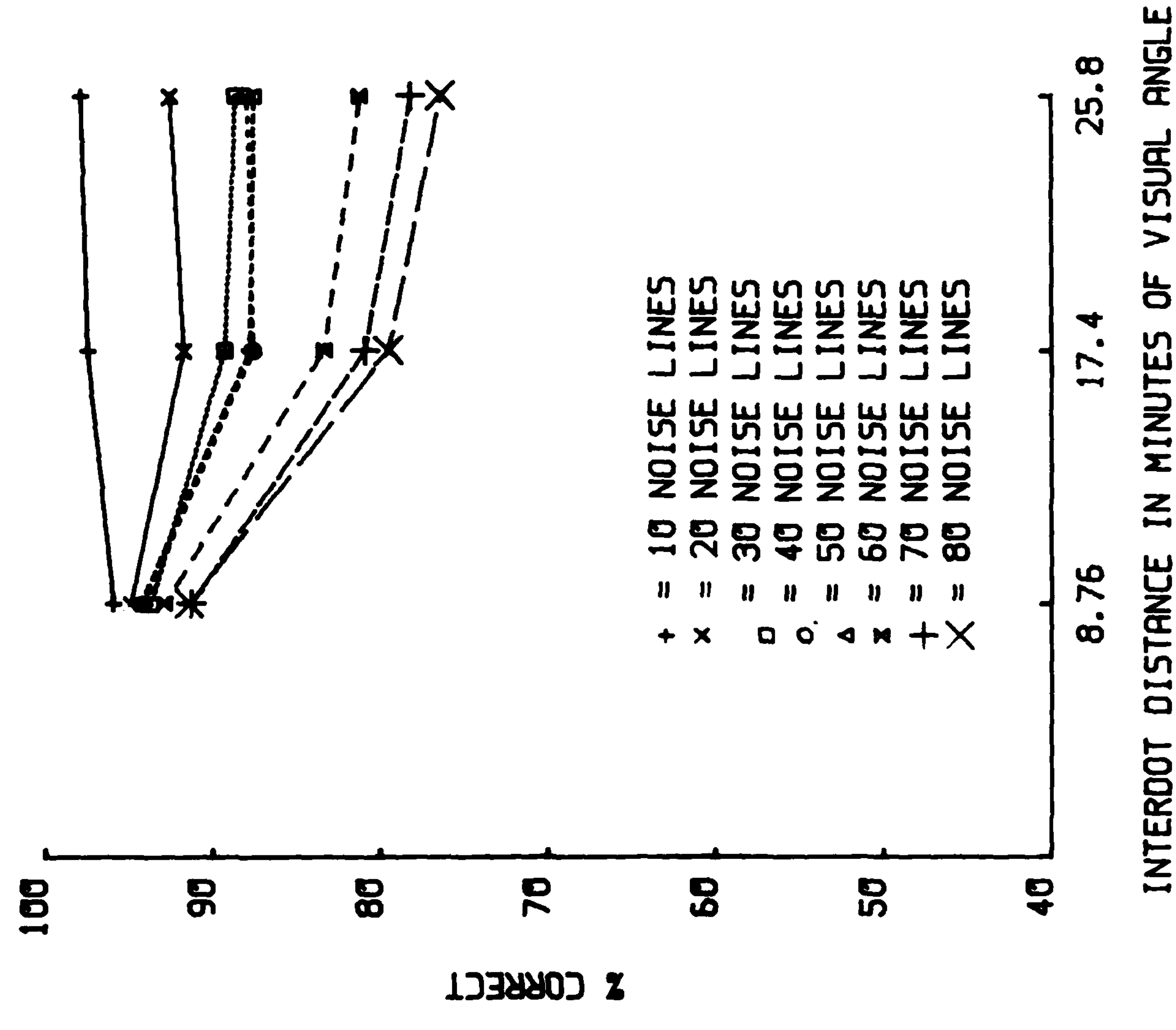
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Figure 8

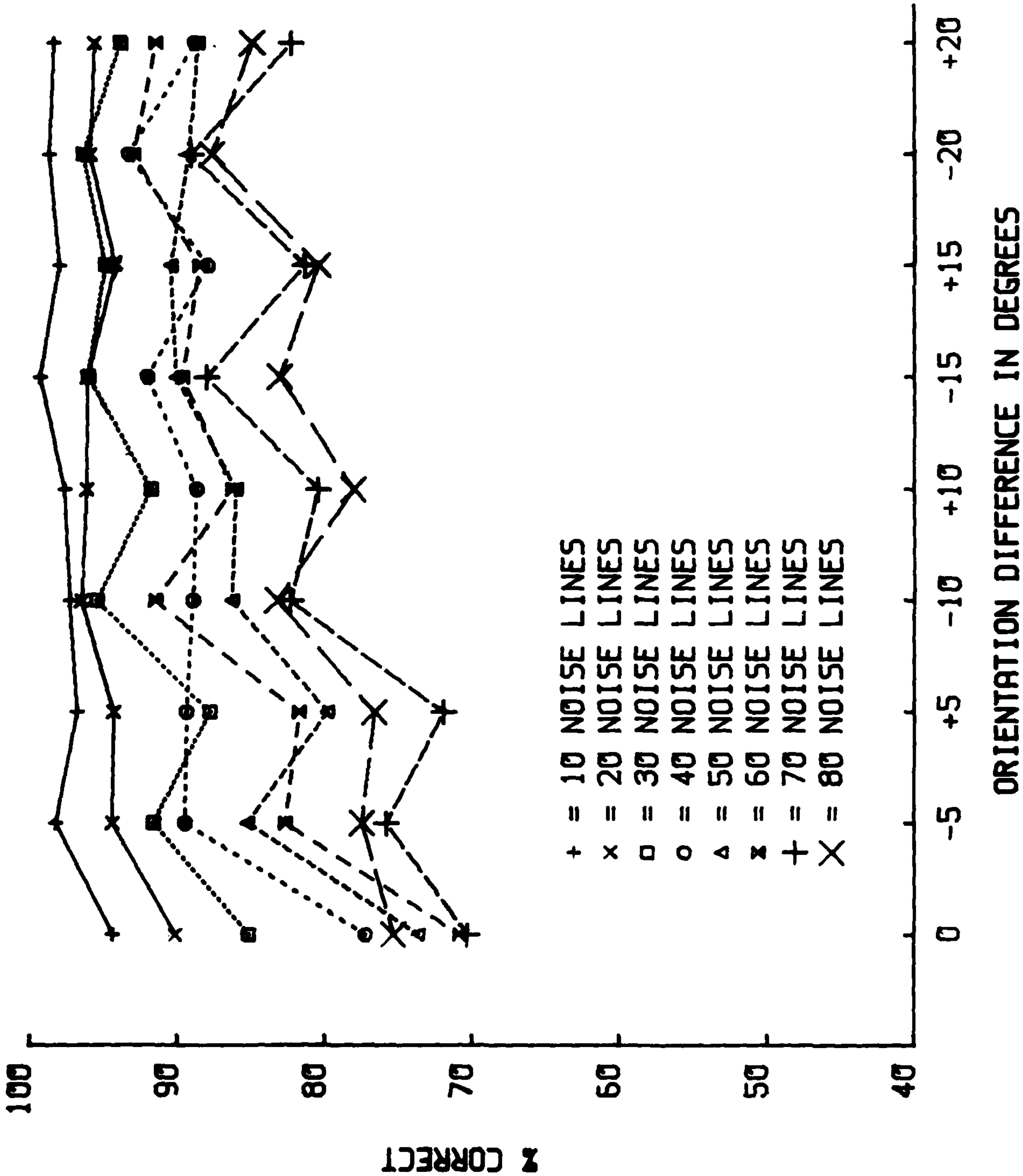
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Figure 9

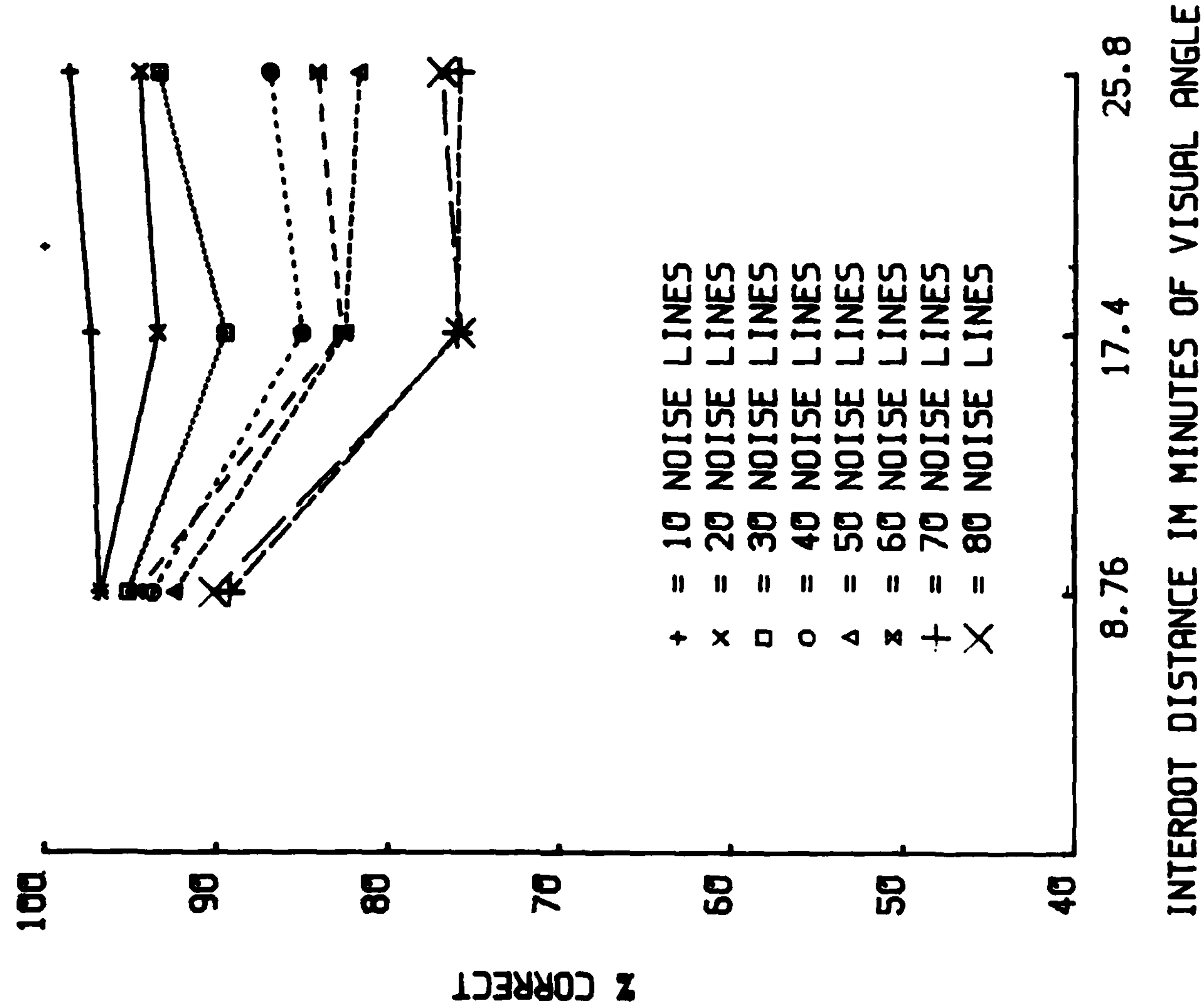
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Figure 10

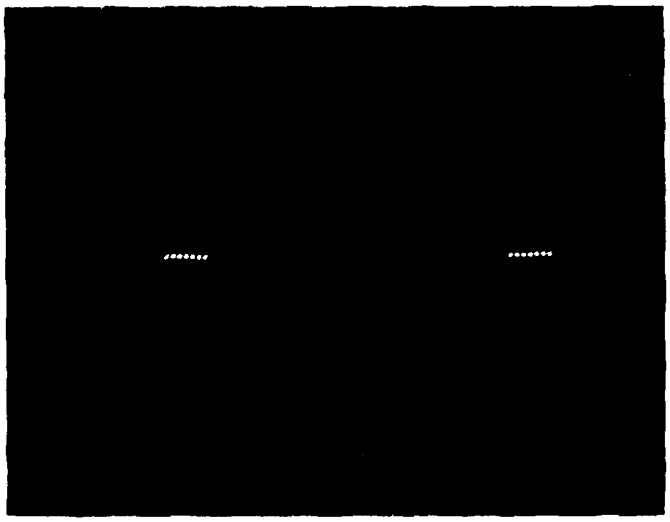
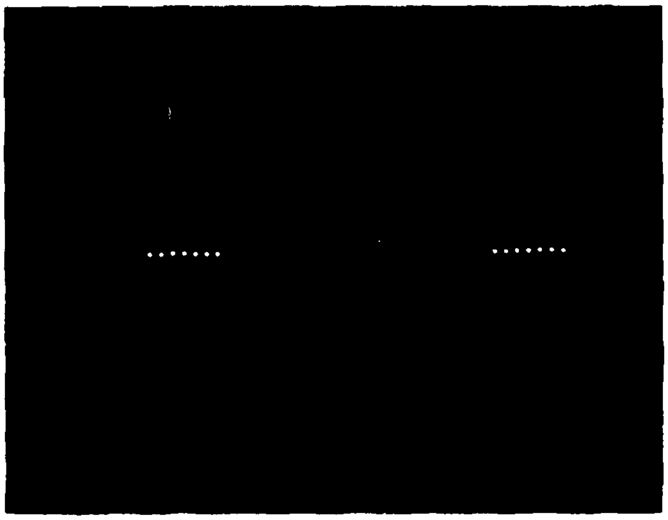


Figure 11 A



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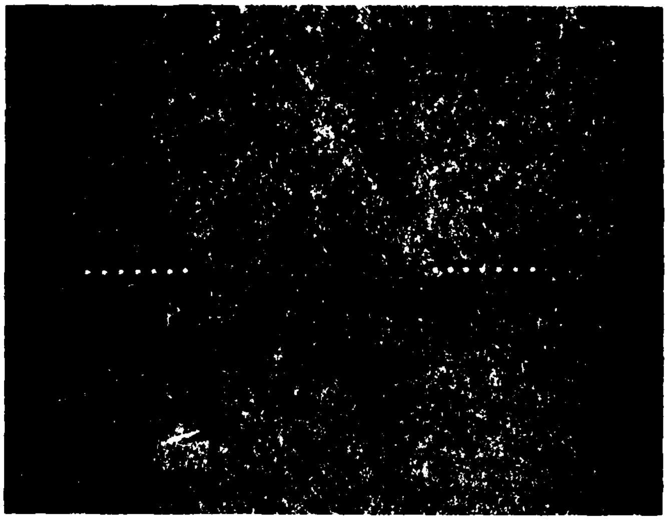

Figure 11 c

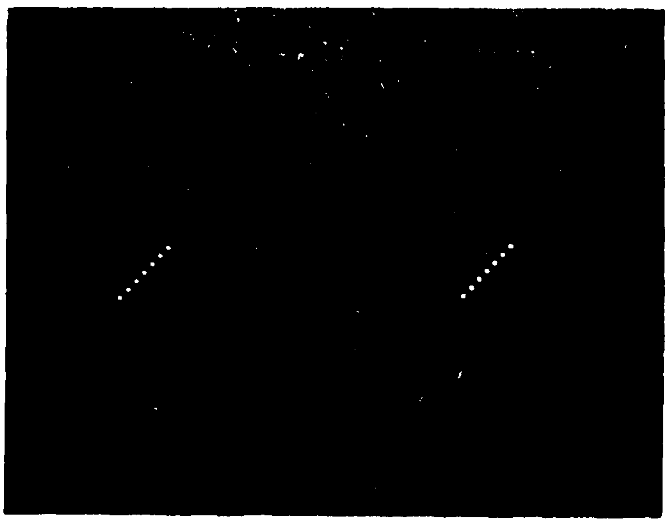

Figure 11 d

Table 1

Number of noise per presentation	Orientation 2,147 d.f.	Local Geometry 2,147 d.f.	Interaction 12,147 d.f.
10 noise lines	F=24.18, p<.01	F=9.0, p<.01	F=2.12, p<.01
20 noise lines	F=33.06, p<.01	F=.38, N.S.	F=.81, N.S.
30 noise lines	F=46.56, p<.01	F=4.88, p<.01	F=.74, N.S.
40 noise lines	F=60.59, p<.01	F=7.4, p<.01	F=.99, N.S.
50 noise lines	F=43.63, p<.01	F=25.18, p<.01	F=1.05, N.S.
60 noise lines	F=38.68, p<.01	F=54.61, p<.01	F=2.46, N.S.

Table 2

Number of noise per presentation	Orientation 2,146 d.f.	Local Geometry 2,146 d.f.	Interaction 12,146 d.f.
10 noise lines	F=4.630, p<.01	F=6.93, p<.01	F=1.57, N.S.
20 noise lines	F=23.48, p<.01	F=5.46, p<.01	F=3.12, p<.01
30 noise lines	F=35.56, p<.01	F=.75, N.S.	F=.66, N.S.
40 noise lines	F=27.43, p<.01	F=1.28, N.S.	F=.55, N.S.
50 noise lines	F=37.76, p<.01	F=5.600, p<.01	F=.960, N.S.
60 noise lines	F=36.29, p<.01	F=6.164, p<.01	F=.633, N.S.
70 noise lines	F=36.18, p<.01	F=13.52, p<.01	F=2.03, N.S.

Table 3

Number of noise per presentation	Orientation 2,135 d.f.	Local Geometry 2,135 d.f.	Interaction 12,357 d.f.
10 noise lines	F=.53, N.S.	F=1.9, N.S.	F=.287, N.S.
20 noise lines	F=.48, N.S.	F=3.14, p<.05	F=.597, N.S.
30 noise lines	F=.35, N.S.	F=4.00, p<.05	F=.93, N.S.
40 noise lines	F=.83, N.S.	F=20.42, p<.01	F=.97, N.S.
50 noise lines	F=1.01, N.S.	F=22.66, p<.01	F=.628, N.S.
60 noise lines	F=.55, N.S.	F=23.66, p<.01	F=.530, N.S.
70 noise lines	F=1.43, N.S.	F=17.19, p<.01	F=.550, N.S.

Table 4

Number of noise per presentation	Orientation 8,162 d.f.	Local Geometry 2,162 d.f.	Interaction 12,162 d.f.
10 noise lines	F=3.050, p<.01	F=.92, N.S.	F=.530, N.S.
20 noise lines	F=9.560, p<.01	F=1.38, N.S.	F=.305, N.S.
30 noise lines	F=9.210, p<.01	F=3.16, p<.05	F=.58, N.S.
40 noise lines	F=17.07, p<.01	F=8.41, P<.01	F=.90, N.S.
50 noise lines	F=11.85, p<.01	F=9.480, p<.01	F=1.40, N.S.
60 noise lines	F=11.14, p<.01	F=15.35, p<.01	F=.555, N.S.
70 noise lines	F=16.24, p<.01	F=20.79, p<.01	F=1.15, N.S.
80 noise lines	F=11.24, p<.01	F=19.99, p<.01	F=.825, N.S.

Table 5

Number of noise per presentation	Orientation 8,162 d.f.	Local Geometry 2,162 d.f.	Interaction 12,162 d.f.
10 noise lines	F=2.820, p<.01	F=3.94. p<.05	F=.590, N.S.
20 noise lines	F=1.240, N.S.	F=3.71, p<.05	F=.730, N.S.
30 noise lines	F=3.210, p<.01	F=7.63, p<.01	F=.51, N.S.
40 noise lines	F=2.140, p<.05	F=8.03, P<.01	F=.34, N.S.
50 noise lines	F=3.050, p<.01	F=10.95, p<.01	F=.450. N.S.
60 noise lines	F=2.860, p<.01	F=16.24, p<.01	F=.950, N.S.
70 noise lines	F=4.40, p<.01	F=18.44, p<.01	F=.805, N.S.
80 noise lines	F=2.470, p<.01	F=17.93, p<.01	F=1.13, N.S.

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